Results from Double Polarization Experiments at ELSA

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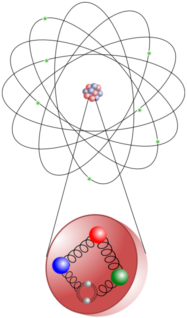
13.01.2014

Structure of Matter: Spectroscopy

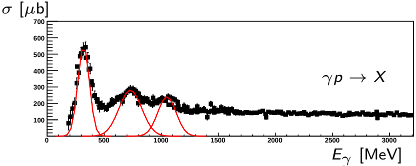
excitation spectrum

Spectroscopy of atoms



→ information about QED

Spectroscopy of hadrons



→ information about QCD

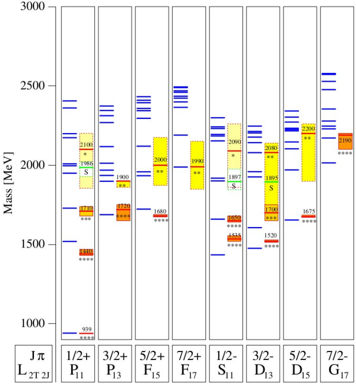
Spectroscopy of Hadrons

Excitation spectrum gives information about the dynamics inside the nucleon (quarks and gluons)

→ Baryon excitation spectrum needs to be understood

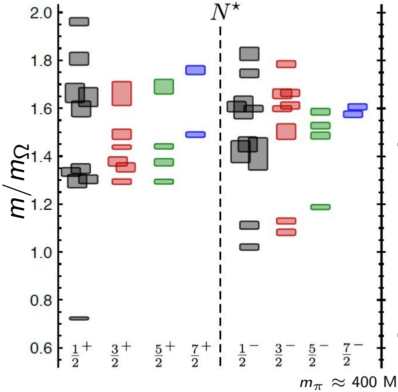
Theoretical Predictions

Quark models



[Löring et al. 2001]

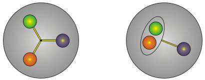
Lattice QCD calculations



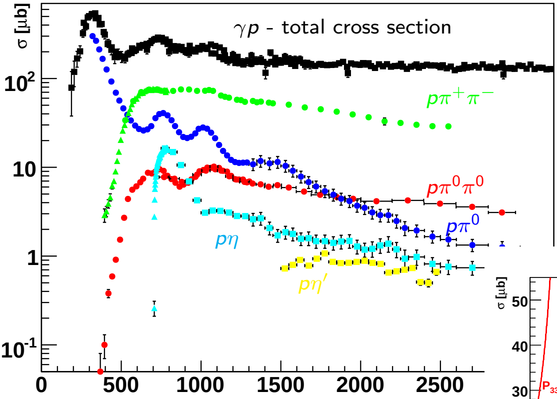
[Edwards et al. 2011]

Calculations predict more resonances than have been measured ("missing resonances")

→ What are the relevant degrees of freedom?

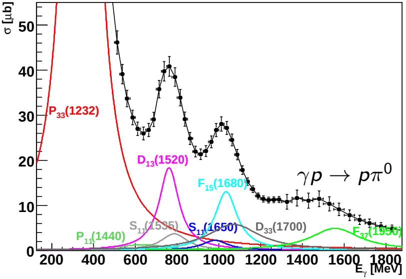


Resonances



Resonances overlap strongly with different strengths and widths
→ Weak resonance contributions difficult to measure

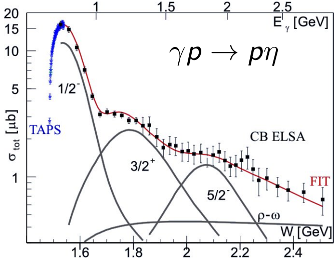
Partial wave analysis needed to disentangle the resonances.



Cross Section

Total cross section:
Sum of different partial waves

$\sigma_{tot} \sim |A_{1/2}(S_{11})|^2 + |A_{1/2}(P_{13})|^2 + |A_{3/2}(P_{13})|^2 + \cdots$



[V. Crede et al.]

Cross Section

Total cross section:
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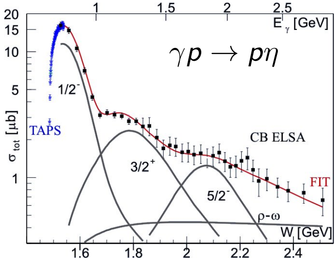


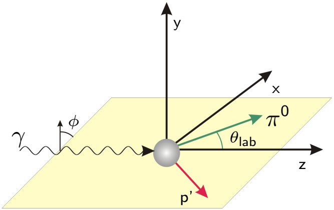
[V. Crede et al.]

Polarization observables sensitive to interference terms:

$$\Sigma \sim A_{1/2}(S_{11}) \cdot A_{1/2}(P_{11}) + \cdots$$

Measurement of polarization observables necessary for a unique solution of the partial wave analysis and to identify small resonance contributions.

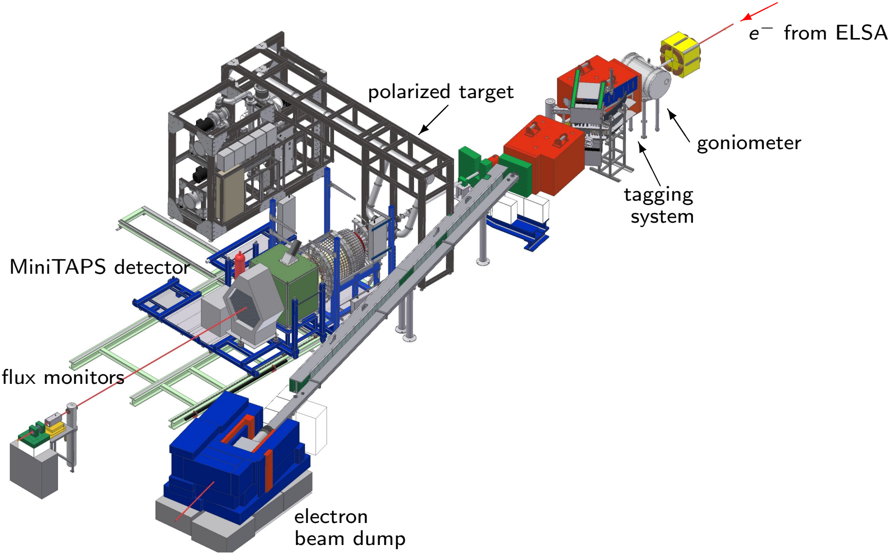
Cross Section with Beam und Target Polarization



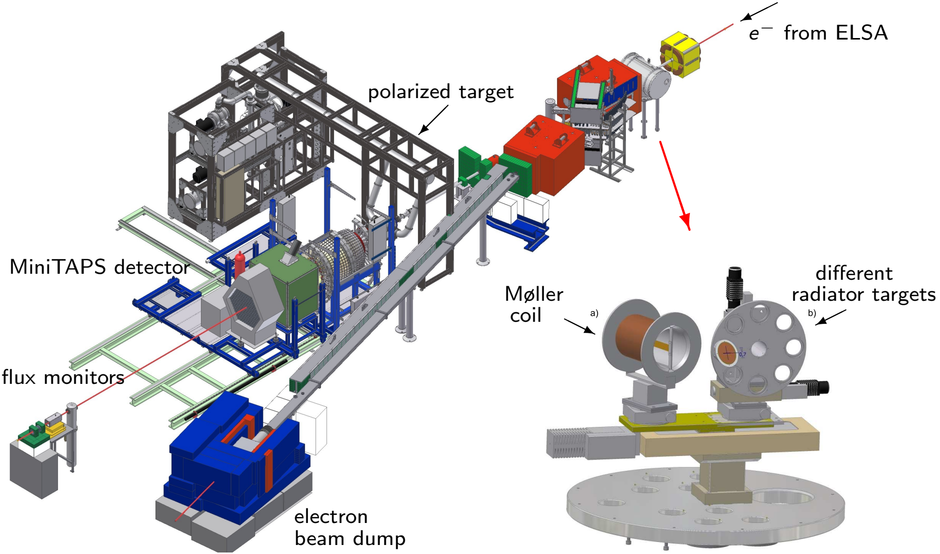
$$\begin{aligned}\frac{d\sigma}{d\Omega} &= \frac{d\sigma}{d\Omega}(\theta)\cdot\Big[1 - p_\gamma^{lin}\Sigma\cos(2\phi)\\ &+ p_x(-p_\gamma^{lin}H\sin(2\phi) + p_\gamma^{circ}F)\\ &- p_y(-T + p_\gamma^{lin}P\cos(2\phi))\\ &- p_z(-p_\gamma^{lin}G\sin(2\phi) + p_\gamma^{circ}E)\Big]\end{aligned}$$

		Target Polarization		
Photon Polarization		x	y	z
unpolarized	σ	–	T	–
linearly polarized	Σ	H	P	G
circularly polarized	–	F	–	E

The Setup of the CBELSA/TAPS Experiment

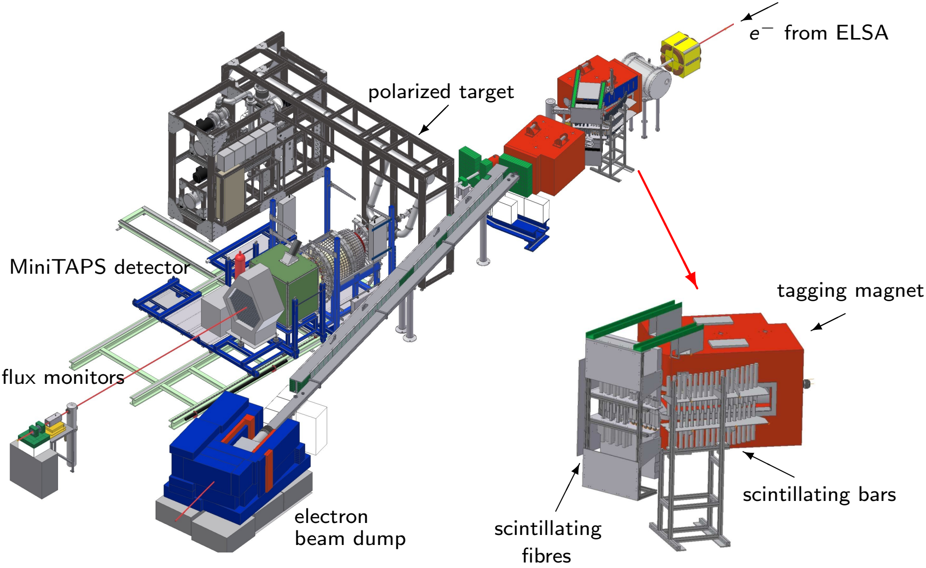


The Setup of the CBELSA/TAPS Experiment

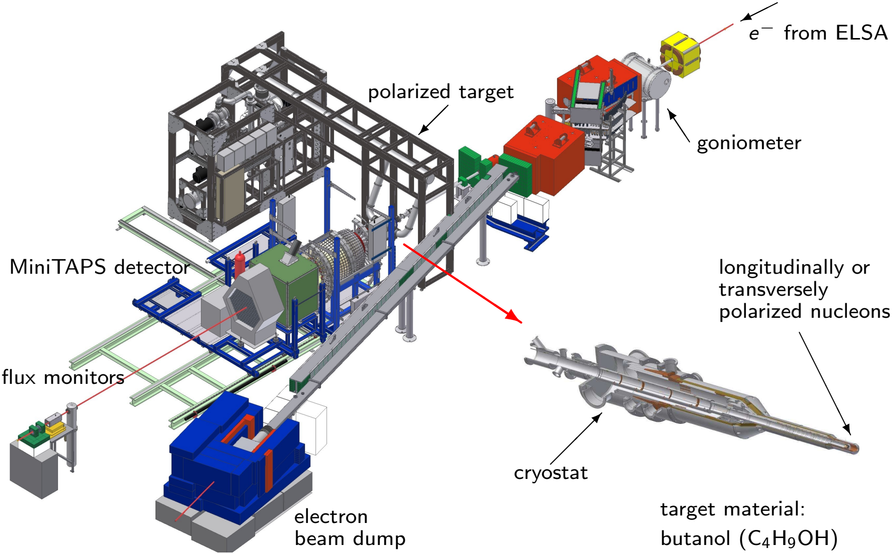


$\rightarrow$ circularly and linearly polarized photons

The Setup of the CBELSA/TAPS Experiment



The Setup of the CBELSA/TAPS Experiment



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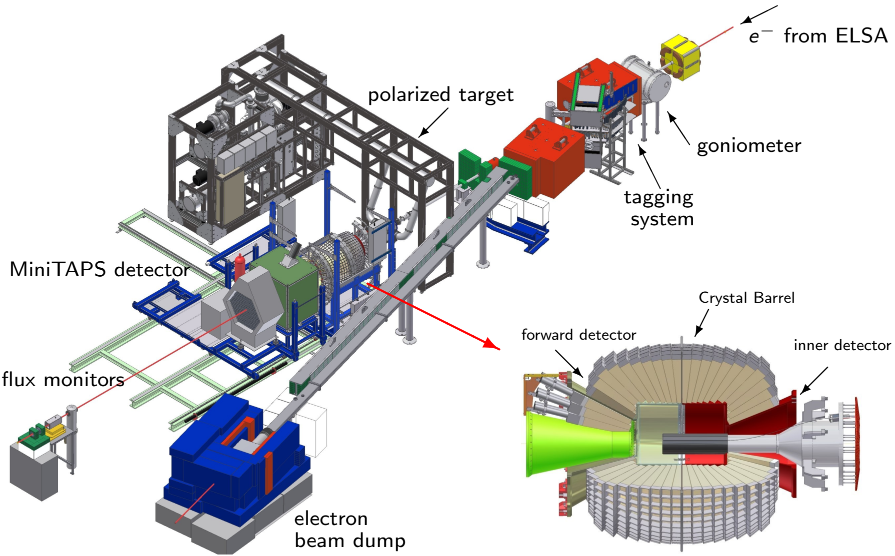
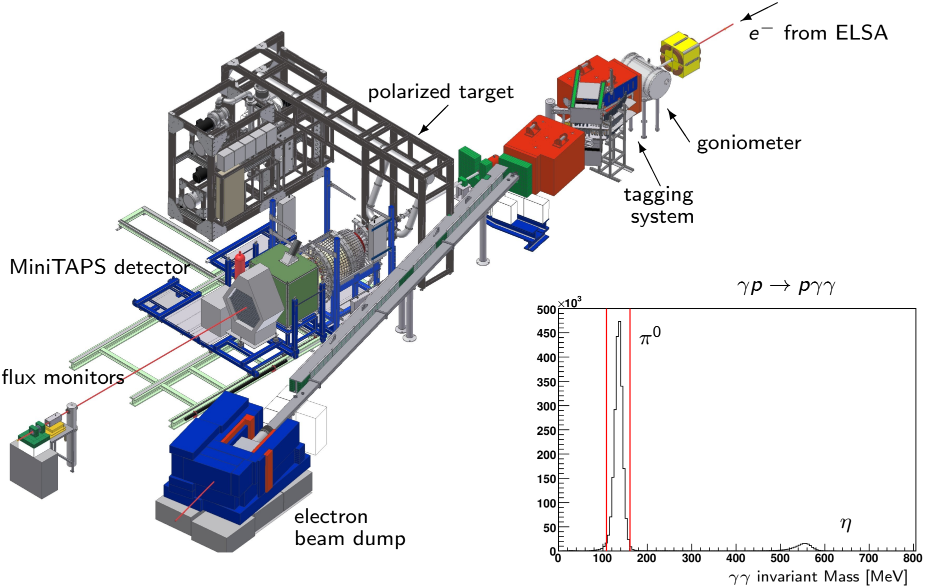
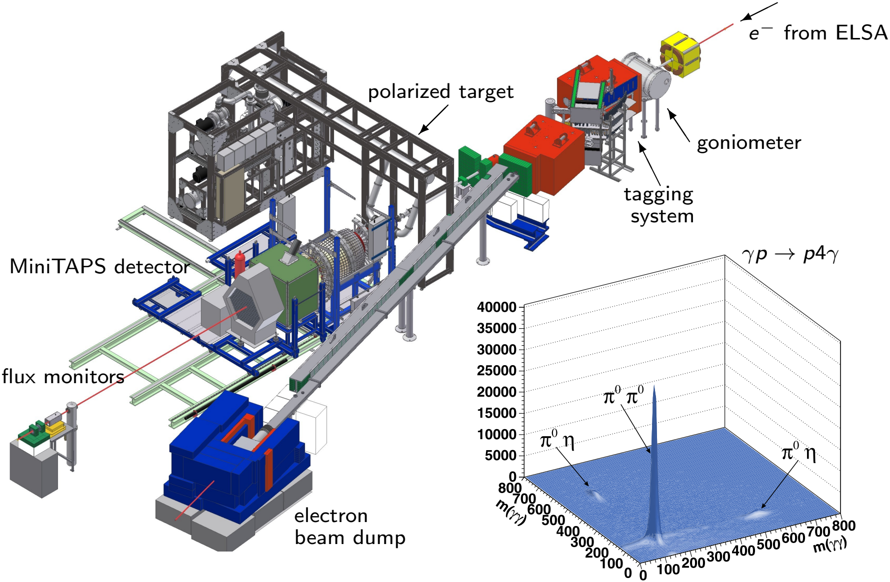


→ nearly full 4π angular coverage

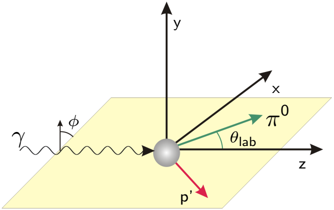
The Setup of the CBELSA/TAPS Experiment



The Setup of the CBELSA/TAPS Experiment



Cross Section with Beam und Target Polarization



$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}(\theta) \cdot \Big[1 - p_\gamma^{lin} \Sigma \cos(2\phi)$$
$$+ \; p_x(-p_\gamma^{lin} H \sin(2\phi) + p_\gamma^{circ} F)$$
$$- \; p_y(-T + p_\gamma^{lin} P \cos(2\phi))$$
$$- \; p_z(-p_\gamma^{lin} G \sin(2\phi) + p_\gamma^{circ} E)\Big]$$

		Target Polarization		
Photon Polarization		x	y	z
unpolarized	σ	–	T	–
linearly polarized	Σ	H	P	G
circularly polarized	–	F	–	E

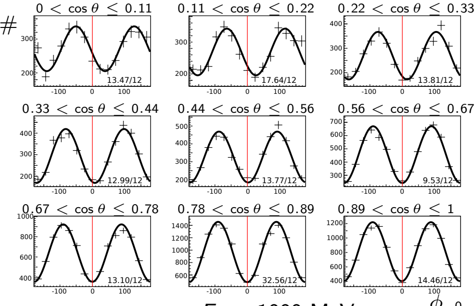
For π^0-photoproduction:
Data published
Data taken

ϕ-Distribution of the Mesons

Cross section with longitudinally polarized target and linearly polarized photons:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}(\theta) \cdot \left[1 - p_\gamma^{lin} \Sigma \cos(2\phi) + p_z p_\gamma^{lin} G \sin(2\phi)\right]$$

$\gamma p \to p\pi^0$

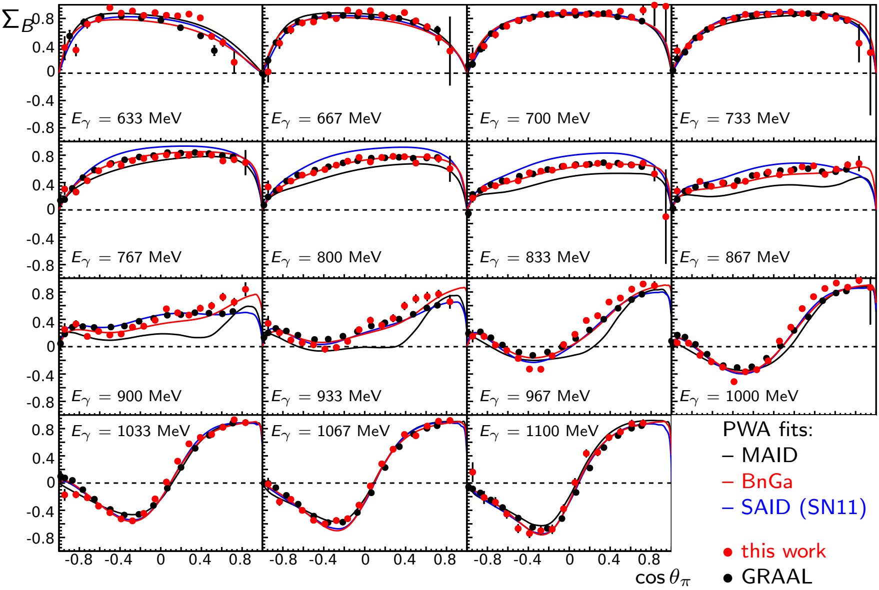


Linear polarization plane

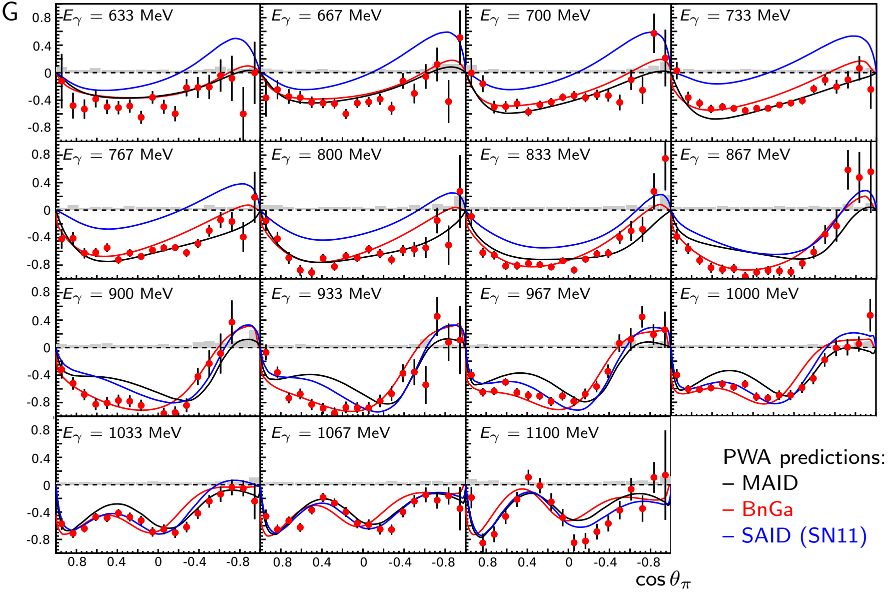
$E_\gamma = 1000$ MeV

- Influence of polarization observables directy visible
- Symmetric around linear polarization plane
  $\rightarrow$ Σ dominating
- Deviation from symmetry
  $\rightarrow$ influence of double polarization observable G

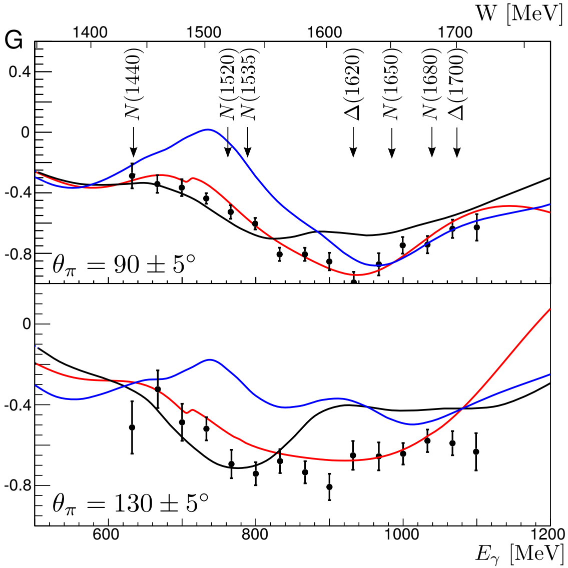
$\gamma p \to p\pi^0$: Beam Asymmetry Σ_B



$\gamma p \to p\pi^0$: Double Polarization Observable G



$\gamma p \to p\pi^0$: Double Polarization Observable G

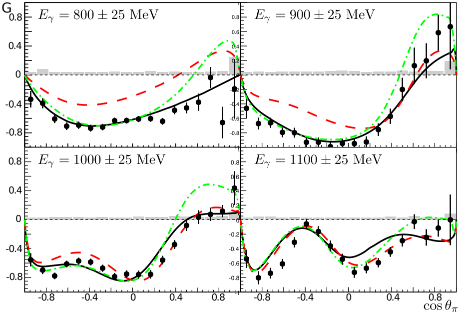


Predictions of the partial wave analyses (PWA) show differences in certain energy regions, can be attributed to E_0^+ and E_2^- multipoles, e.g. S_{11} resonances

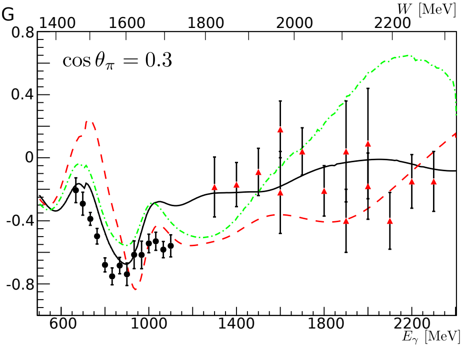
PWA Predictions:
MAID
BnGa
SAID (SN11)

A.Thiel et al., PRL 109 (2012) 102001

New Solution from SAID



- New solution from SAID (CM12) with new fit method but same data input
- Better description to the data in most angular regions



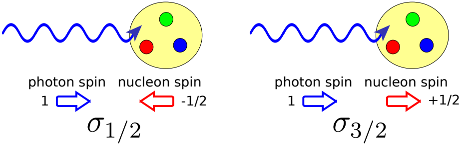
– BnGa
– SAID (SN11)
– SAID (CM12)

- this work
- Bussey et al.

A.Thiel et al., Phys. Rev. Lett. 110, 169102 (2013).

The Double Polarization Observable E

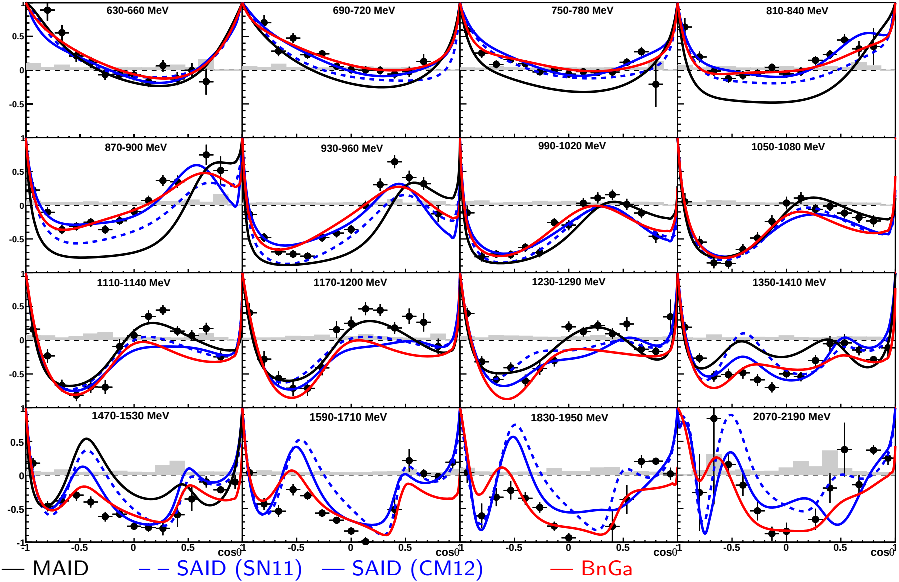
- Observable is a helicity asymmetry
- Two spin configurations possible:



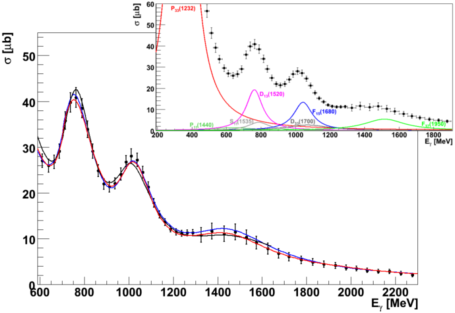
$$E(\theta, E_\gamma) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

$\gamma p \rightarrow p\pi^0$: Double Polarization Observable E

M. Gottschall et al., Phys. Rev. Lett. 112, 012003 (2014)

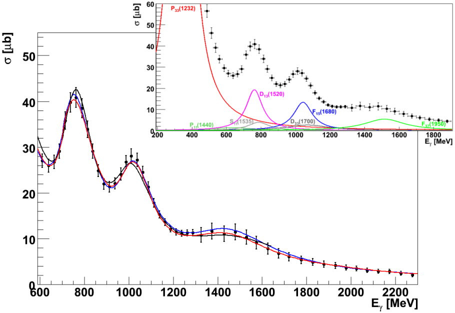


$\gamma p \rightarrow p\pi^0$: $\sigma_{1/2}$ vs. $\sigma_{3/2}$

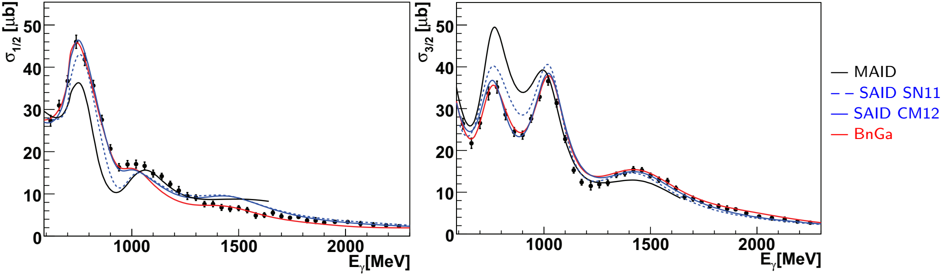


- Different models show good description of the cross section
- Spin dependent cross section can be extracted: $\sigma^{1/2(3/2)} = \sigma_0 \cdot (1 \pm p_T p_\gamma E)$

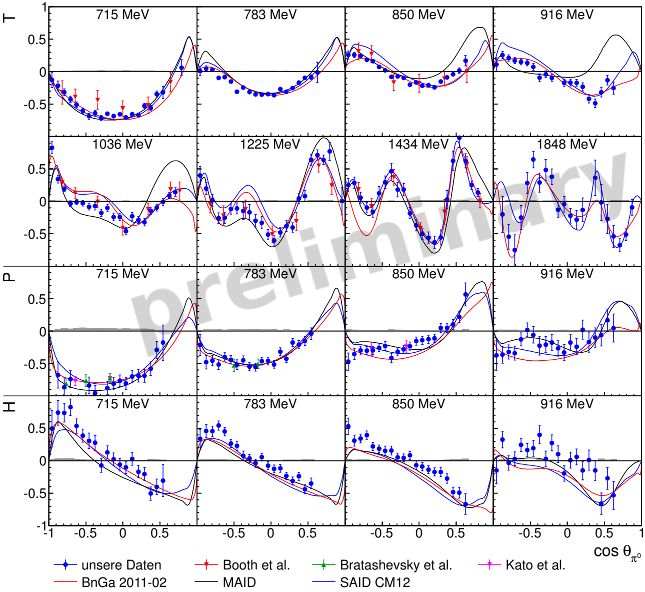
$\gamma p \rightarrow p\pi^0$: $\sigma_{1/2}$ vs. $\sigma_{3/2}$



- Different models show good description of the cross section
- Spin dependent cross section can be extracted: $\sigma^{1/2(3/2)} = \sigma_0 \cdot (1 \pm p_T p_\gamma E)$
- Large differences occur in $\sigma^{1/2}$ and $\sigma^{3/2}$ cross sections



$\gamma p \to p\pi^0$: Polarization Observables T, P and H



Transversly polarized target lead to several new observables

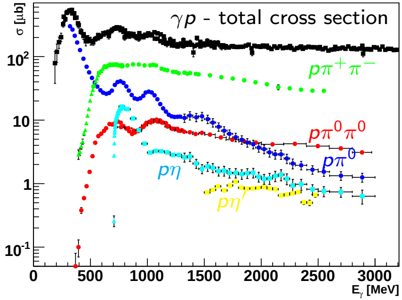
High quality data set with large angular coverage and wide energy range

Only selected bins shown here

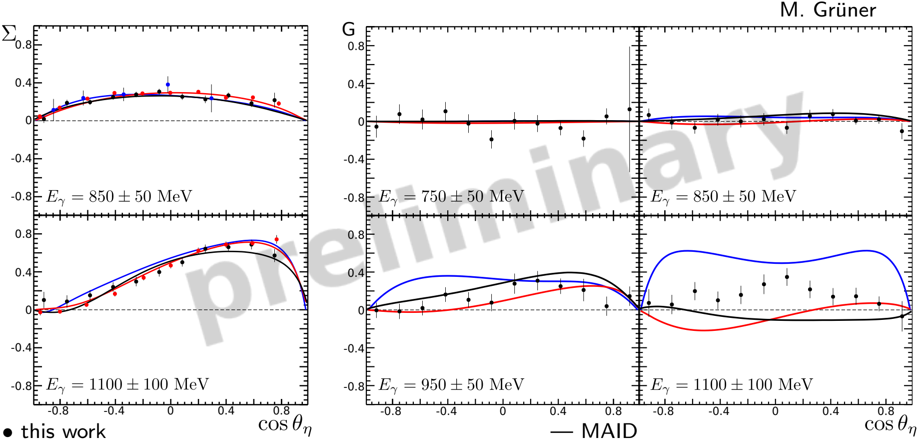
Extraction of observables for different final states

- Photoproduction off neutrons necessary for isospin separation (see talk by B. Krusche on wednesday)

- Many final states in photoproduction possible, important to measure them
- η and η' photoproduction can work as isospin filters, only resonances with $T = 1/2$ can contribute



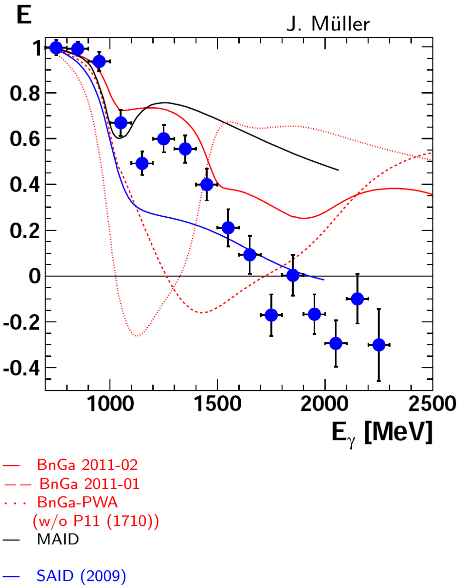
$\gamma p \to p\eta$: Polarization Observables Σ and G



- this work
- GRAAL
- D. Elsner (CBELSA/TAPS)

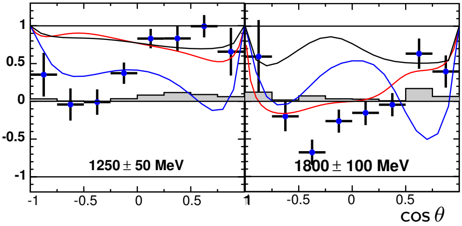
— MAID
— SAID (SN11)
— BnGa

$\gamma p \to p\eta$: Double Polarization Observable E



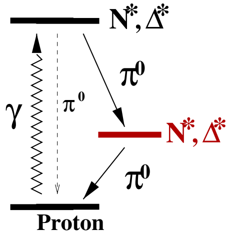
$$E(\theta, E_\gamma) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

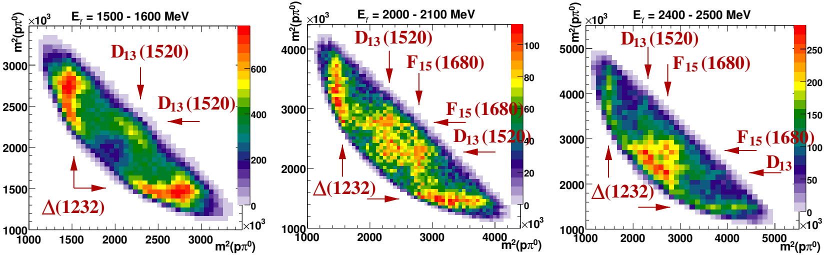
- At threshold: E close to 1 due to $S_{11}(1535)$ dominating
- At higher energies: large discrepancies in the predictions



Observables in Multi-Meson Final States

- Multi-meson final states like $\gamma p \rightarrow p\pi^0\pi^0$ or $\pi^0\eta$ preferred at higher energies
- Probes the high mass region, where the missing resonances occur
- Can help to observe cascading decays

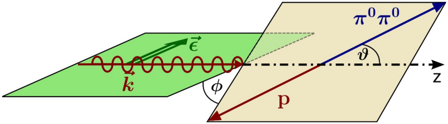




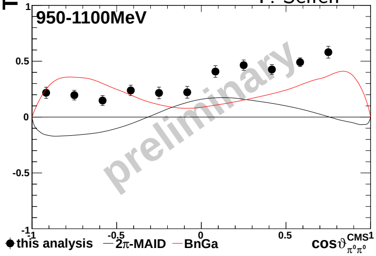
V. Sokhoyan

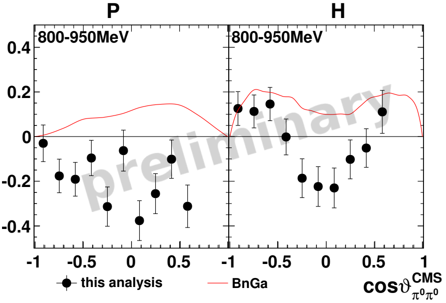
$\gamma p \to p\pi^0\pi^0$: Polarization Observables T, P, H

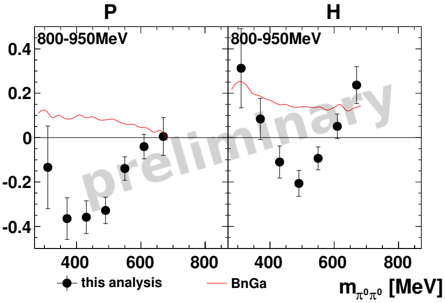
- Here: only results shown in quasi two-body kinematics



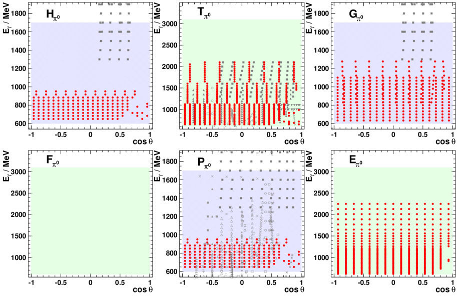
T. Seifen







Measured Datasets in π^0 Photoproduction

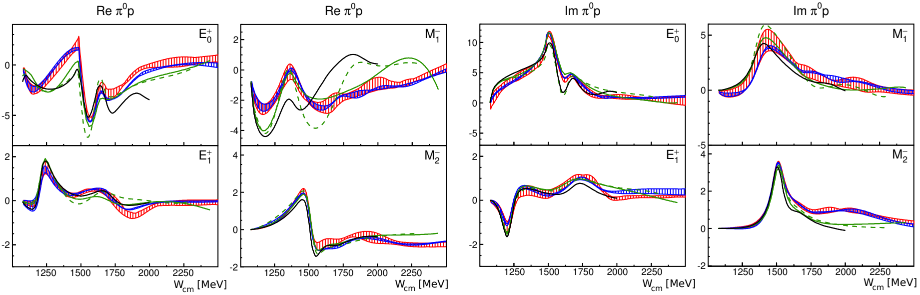


Photon Polarization		Target Pol. x	y	z
unpolarized	σ	–	T	–
linearly polarized	Σ	H	P	G
circularly polarized	–	F	–	E

- Nearly full dataset available now for π^0 photoproduction

$\rightarrow$ New datapoints fitted by the BnGa PWA

Preliminary Fit from BnGa

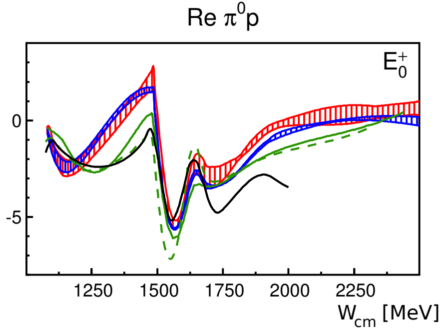


MAID, SAID CM12 (solid) SN11 (dashed), BnGa, BnGa with double pol. obs.

- By using additional observables, the fit error bands get smaller
- Still large differences in the different PW analyses visible

$\rightarrow$ Including more polarization observables will converge all analyses to the same solution

Preliminary Fit from BnGa



MAID, SAID CM12 (solid) SN11 (dashed), BnGa, BnGa with double pol. obs.

- By using additional observables, the fit error bands get smaller
- Still large differences in the different PW analyses visible

→ Including more polarization observables will converge all analyses to the same solution

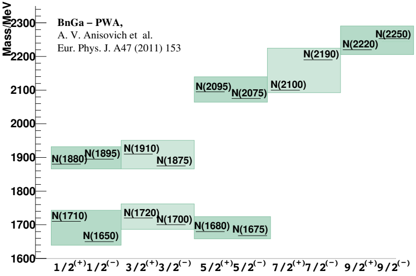
Comparison between PDG values and BnGa results

- Until 2010: almost only results from pion nucleon scattering used in the PDG, only few pion photoproduction data used
- Now: new values from the BnGa fits are now entering the PDG

	PDG 2010	BnGa-PWA	PDG 2012	GWU'06
$N(1860)5/2^+$		*	**	
$N(1875)3/2^-$		***	***	
$N(1880)1/2^+$		**	**	
$N(1895)1/2^-$		**	**	
$N(1900)3/2^+$	**	***	***	no evidence
$N(2060)5/2^-$		***	**	
$N(2150)3/2^-$		**	**	
$\Delta(1940)3/2^-$	*	*	**	no evidence

Still Many Open Questions...

- Parity doublets occuring at low energies, also at higher energies? They are not predicted by the current lattice QCD calculations nor by constituent quark models.



- Still many missing resonances. Why haven't we found them yet?

- Is it possible to do a complete experiment? How many observables and which precision is needed?

Conclusion

- Reactions like $\gamma p \rightarrow p\pi^0$, $p\eta$, $p\eta'$, $p\omega$, $p\pi^0\pi^0$, $p\pi^0\eta$ have been measured with polarized photons and protons at ELSA
- Different single and double polarization observables have been successfully extracted over a wide energy range
- Data for the observables Σ, G and E has been published for π^0 photoproduction

Conclusion and Outlook

- Reactions like $\gamma p \rightarrow p\pi^0$, $p\eta$, $p\eta'$, $p\omega$, $p\pi^0\pi^0$, $p\pi^0\eta$ have been measured with polarized photons and protons at ELSA
- Different single and double polarization observables have been successfully extracted over a wide energy range
- Data for the observables Σ, G and E has been published for π^0 photoproduction
- Further final states and photoproduction off the neutron needed (see talk by B. Krusche)
- Several other experiments (CLAS, Crystal Ball/MAMI, BGO-OD) will help to create a comprehensive database of polarization observables in different reactions
- New polarization data will help to understand the resonance spectrum and will provide an experimental basis for comparison with constituent quark models, lattice QCD or other methods

Thank you
for your attention.